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AF 1765

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: Binqiang Shi	)	Group Art Unit: 1765
Patent Application No.: 09/851,839	)	Examiner: Nadine G. Norton
Filed: May 9, 2001	)	Re: REPLY BRIEF
	)	Our Ref: B-3945 617918-2
For: "NOVEL EPITAXY WITH COMPLIANT LAYERS OF GROUP-V SERIES"	)	Date: May 18, 2004

REPLY BRIEF

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

This paper is a Reply Brief to the Examiner's Answer issued on March 18, 2004 for the above-referenced patent application. Please enter the following remarks into the prosecution history of the above-mentioned application. **All remarks herein are made without prejudice.**

REMARKS

The comments in the Appeal Brief filed on December 29, 2003 are incorporated herein by reference.

1. Claims 1 - 11, 25 - 27, 29 - 31, and 39 - 40 rejected under 35 U.S.C. 103(a) as being unpatentable over Pessa et al., U.S. Patent No. 4,876,218 (hereinafter "Pessa") in view of Hayakawa et al. U.S. Patent No. 4,824,518 (hereinafter "Hayakawa")

Claim 1

The Appellants object to the Examiner's attempt to misquote the Appellants' arguments. The Appellants submit that nowhere in the Appeal Brief did the Appellants suggest that the strain is accommodated entirely by the first layer as asserted by the Examiner on page 11, lines 8-10 of the Examiner's answer. On the contrary, the Applicant has always asserted, as is claimed in Claim 1, that "the first layer substantially accommodates strain", page 17, lines 23-24 of the Appeal brief.

The Applicant respectfully submits that the Examiner did not to establish a *prima facie* case of obviousness of a claimed invention by **failing** to show that all the limitations of the Claim 1 are taught or suggested by the prior art. "To establish prima facie obviousness of a claimed invention, **all** the claim limitations must be taught or suggested by the prior art" (emphases added) In re Royka, 490 F.2d 981 and MPEP §2143.03. Despite the Appellants' clear articulation of the issue in the Appeal Brief pages 17-18, the Examiner fails to consider in its entirety the limitation of Claim 1 that states "... the first layer **substantially** accommodates strain accumulated between the first crystal and the second crystal during epitaxial growth ..." (emphases added). The Examiner wrongly interprets this limitation as "the first layer merely has to accommodate **any** amount, which can be very small, of the strain between the first crystal and the second crystal during epitaxial growth", page 11, lines 7-8 of the Examiner's answer. The complete language of Claim 1 does not support the Examiner's interpretation.

Claim 1 specifically states that "the first layer **substantially** accommodates strain" (emphases added). It is not clear why the Examiner chooses not to consider all the words in Claim 1 as was required by CCPA in In re Wilson. According to In re Wilson "**[a]ll** words in a claim must be considered in judging the patentability of that claim against the prior art" (emphases added) In re Wilson, 424 F.2d 1382, 1385.

The Appellants submit that Claim 1, considered in its entirety, is **not** taught or suggested by Pessa in view of Hayakawa for the following reasons. The Examiner admits that "Pessa is not limited to a two atom thick buffer layer", page 12, lines 7-8 of the Examiner's answer and the Examiner agrees that "the strain relief is distributed over all of the layers [described in Pessa's buffer layer]", page 12, lines 8-10 of the Examiner's answer. Therefore, since the strain is distributed over **all** the layers in Pessa, the first layer in Pessa does not "**substantially** accommodate strain accumulated between the first crystal and the second crystal" as claimed in Claim 1. At best, a pair of layers in Pessa only accommodates strain between the layers to which it is immediately adjacent. Those layers do not meet the first and second crystal of Claim 1.

The Figure in Appendix A clearly demonstrates the Examiner's misinterpretation of Claim 1 (this figure is for demonstration purposes only and is not part of the present application). Pessa teaches that the thickness of the buffer layer may vary within a range from 4 to 300 nm, preferably from 50 to 150 nm, see column 4, lines 5-9 of Pessa. That translates to a minimum and maximum thickness of 40 Å to 3000 Å. The buffer layer as taught by Pessa is made up of stacking single atom Ga layers over single atom As layers. See column 3, lines 60-64 of Pessa. Since the calculated Atomic radius of the Ga

is 1.36 Å and the calculated Atomic radius of the As is 1.14 Å, see enclosed printouts from www.webelements.com, it would require anywhere from 32 to 1200 layers of Ga stacked over As to create the desired buffer layer as taught by Pessa. This is supported by the Examiner's statement that "Pessa is not limited to only four layers". See page 11, line 18 of the Examiner's answer. The Figure in Appendix A depicts the two crystals and a buffer layer made up of one hundred Ga and As single atom layers as taught by Pessa. The Appellants submit that in a structure made up of one hundred single atom layers, as taught by Pessa, each individual layer would accommodate only a small fraction, probably around 1%, of the entire strain accumulated between the first and second crystals, as shown by the Figure in Appendix A. Obviously, layer 1 of the Figure does not "substantially accommodate strain accumulated between the first crystal and the second crystal" as required by Claim 1.

The Examiner asserts that in a structure such as that shown by the Figure in Appendix A, the single atom layer adjacent the first crystal will "substantially accommodate strain accumulated between the first crystal and the second crystal" as recited by Claim 1. The Examiner cites nothing to support this unorthodox contention.

As stated in the Appeal Brief, the Examiner failed to provide any evidence to support his beliefs, which the applicant believes are unorthodox, even when the applicant called upon the Examiner to cite some reference or to provide an Affidavit supporting his views. The Examiner failed to comply with the rules of practice, particularly 37 C.F.R. 1.104(d)(2) and supply the Affidavit specifically setting forth the facts upon which he relies in rejecting Claim 1. See page 18, last paragraph of the Appeal Brief.

The Applicant further submits that the Examiner did not to establish a *prima facie* case of obviousness of a claimed invention because "it is improper to combine references where the references teach away from their combination" MPEP 2145(X)(D)(2) and In re Grasselli, 713 F.2d 731, 743.

Pessa teaches away from Hayakawa for the following reasons. Hayakawa teaches the deposition of the As on a clean surface to prevent "the residual gas from adhering to the surface of the GaAs substrate while the GaAs substrate is carried from the pre-treatment chamber 3 to the growth chamber 4". See column 4, lines 63-67 of Hayakawa. Once the GaAs substrate is in the growth chamber 4, "[t]he growth [of high-quality crystals on the substrate] is started at a relatively low temperature in order to prevent as much deterioration of the GaAs substrate as possible resulting from the **removal** of As therefrom" (emphases added). See column 5, lines 11-16 of Hayakawa. Even though Hayakawa teaches deposition of the As on the substrate, it is done outside of the growth chamber as a temporary "protective film", as stated at column 4, line 63 of Hayakawa, and As is removed before the growth of high-quality crystals on the substrate is started.

Unlike Hayakawa, Pessa teaches that "the shutter 6 is opened in front of the As cell and the vapor beam (As_4 molecules) is allowed to act on the surface of the substrate 1 for a period of time which is required for the formation of one atom layer". See column 3, lines 40-44 of Pessa. It is unclear how the Examiner expects an ordinary person skilled in the art to combine Pessa and Hayakawa when Hayakawa teaches the complete removal of As before the growth of high-quality crystals while Pessa teaches the formation of multiple one atom thick As layers. How is a person of ordinary skill supposed to deal with this glaring inconsistency of approach?

The Examiner has obviously used a hindsight reconstruction approach in making this rejection. The motivation for combining these references comes from Applicant's claims and not the prior art.

Hence, the Examiner failed to establish a *prima facie* case of obviousness. Therefore, Claim 1 is patentable over Pessa and Hayakawa and should be allowed. Claims 2-26 and 39, at least based on their dependency in Claim 1, are also believed to be patentable over Pessa and Hayakawa.

2. Claims 12 - 16 and 18 - 22 rejected under 35 U.S.C. 103(a) as being unpatentable over Pessa in view of Hayakawa and further in view of Ogasawara U.S. Patent No. 4,897,367 (hereinafter "Ogasawara")

The Appellants submit that the Examiner failed to establish a prima facie case of obviousness based on Ogasawara, and the claims are patentable over Ogasawara. The cited reference Ogasawara is improper because it is non-analogous art. Ogasawara is non-analogous art for the following reasons. Ogasawara teaches a process of growing Gallium Arsenide (GaAs) on a Silicon Substrate (Si). Silicon belongs to group-IV species unlike the group III-V species substrate claimed in Claim 15 of the present application. The Examiner asserts that "[i]n this case, Ogasawara et al teaches the formation of GaAs, which is the same material being formed by Pessa, Hayakawa and appellants; therefore is analogous art" at page 15, lines 1-3 of the Examiner's answer. The Examiner correctly states that "it has been held that a prior art reference must either be in the field of applicant's endeavor or, if not, then be reasonably pertinent to the particular problem with which the applicant was concerned, in order to be relied upon as a basis for rejection of the claimed invention" on page 14, lines 18-21 of the Examiner's answer.

However, "a reference is reasonably pertinent if ... it is one which, because of the matter with which it deals, logically would have commended itself to an inventor's attention in considering his problem" In re Clay, 966 F.2d 656, 659. The Appellants submit that Ogasawara is not reasonably pertinent because a person of ordinary skill in the art knows that a group-IV species have different characteristics and properties from group III-V species, therefore, a person of ordinary skill in the art would not look to group-IV species art when trying to improve group III-V crystal growth. It is the Appellants' belief that the only reason Ogasawara was cited was because the Examiner has performed an *ex post facto* analysis of the Applicant's claims. Ogasawara is non-analogous art and a person trying to improve group III-V crystal growth would not look to it.

The Applicant further submits that the Examiner did not to establish a *prima facie* case of obviousness of a claimed invention because "it is improper to combine references where the references teach away from their combination" MPEP 2145(X)(D)(2) and In re Grasselli, 713 F.2d 731, 743.

Like Pessa, Ogasawara teaches away from Hayakawa for the following reasons. Hayakawa teaches the deposition of the As on a clean surface to prevent "the residual gas from adhering to the surface of the GaAs substrate while the GaAs substrate is carried from the pre-treatment chamber 3 to the growth chamber 4". See column 4, lines 63-67 of Hayakawa. Once the GaAs substrate is in the growth chamber 4, "[t]he growth [of high-quality crystals on the substrate] is started at a relatively low temperature in order to prevent as much deterioration of the GaAs substrate as possible resulting from the **removal** of As therefrom" (emphases added). See column 5, lines 11-16 of Hayakawa. Even though Hayakawa teaches deposition of the As on the substrate, it is done outside of the growth chamber as a temporary "protective film", as stated at

column 4, line 63 of Hayakawa, and As is removed before the growth of high-quality crystals on the substrate is started.

Unlike Hayakawa, Ogasawara teaches that "the As beam is irradiated to prevent out-diffusion of As from the GaAs layer 2 when heated". See column 2, lines 66-68 of Ogasawara. It is unclear how the Examiner expects an ordinary person skilled in the art to combine Ogasawara and Hayakawa when Hayakawa teaches the complete removal of As before the growth of high-quality crystals while Ogasawara teaches adding the As to prevent out-diffusion. How is a person of ordinary skill supposed to deal with this glaring inconsistency of approach?

Claim 12

The Examiner's argument that Examiner's conclusions are not based on improper hindsight reasoning is traversed next. The Examiner asserts that "it must be recognized that any judgment on obviousness is in a sense necessarily a reconstruction based upon hindsight reasoning. But, so long as it takes into account only knowledge which was within the level of ordinary skill at the time the claimed invention was made, and does not include knowledge gleaned only from the applicant's disclosure, such a reconstruction is proper" page 16, lines 2-6 of the Examiner's answer. The Applicant submits that the following knowledge was available to the person of ordinary skill at the time the claimed invention was made. As asserted by the Examiner, at page 15, lines 16-18 of the Examiner's answer, "Ogasawara teaches **while still** irradiating an As beam on a substrate to prevent out-diffusion", and Hayakawa teaches the As pressure of 0.013 to 0.0013 Pa, at page 15, lines 20-21 of the Examiner's answer. However, as stated above, Hayakawa also teaches complete removal of As before the growth of high-quality

crystals. It is not clear from the Examiner's statements what would be the motivation to combine Hayakawa and Ogasawara and obtain "annealing the second layer ... under a pressure of the first vapor of about 0.008 pa" as claimed in Claim 12, unless the knowledge was gleaned only from the Appellants' Claim 12.

The Examiner is using the claim as a road map to interpret a prior art document as opposed to considering what the document really teaches to a person skilled in the art. Further, the Examiner fails to show motivation to combine these references. The Examiner is using hindsight to combine a large number of references in a complex manner to arrive at the claimed invention which otherwise would be an onerous task for one skilled in the art.

Hence, the Examiner failed to establish a *prima facie* case of obviousness. Therefore, Claim 12 is patentable over Pessa, Hayakawa and Ogasawara and should be allowed. Claims 13-16 and 18-22, at least based on their dependency in Claim 12, are also believed to be patentable over Pessa Hayakawa and Ogasawara.

Claim 16

Referring to Claim 16, the Examiner asserts at page 6, last paragraph of the Examiner's answer that:

> "the combination of Pessa et al., Hayakawa et al and Ogasawara teaches a first crystal of GaAs and a first material As_4 and a second material of Ga. The combination of teaches [sic] the vapor has a temperature of 800°C ... The sole difference between the prior art and the claimed limitation is the pressure and the temperature of the vapor. The selection of reaction parameters such as temperature and concentration is obvious (In re Aller 105 USPQ 233, 255 (CCPA 1955)). Pressure is well known in the art to be a result effective variable".

However, more recent decisions of the CCPA provide exceptions to the general rule set forth in In re Aller. The Examiner overlooks the In re Sebek case and the In re Antonie case. Contrary to the Examiner, "while it may ordinarily be the case that the determination of optimum values for the parameters of a prior art process would be at least prima facie obvious, that conclusion depends upon what the prior art discloses with respect to those parameters." See In re Sebek 465 F.2d 904, 907; 175 USPQ 93, 95 (CCPA 1972). In the case of In re Antonie 559 F.2d 618; 195 USPQ 6 (CCPA 1977), the parameter (treatment capacity) in question was found not to be result-effective because "[t]he experiments suggested by El-Naggar do not reveal the property which applicant has discovered, and the PTO has provided ... [the court] with no other basis for the obviousness of the necessary experiments." See *Id.*, 195 USPQ at 8. Unlike Claim 16, the Examiner concedes that "[t]he combination of Pessa et al, Hayakawa et al and Ogasawara is silent to the pressure of the second vapor", see page 6, lines 16-17 of the Examiner's answer, and the Examiner has not provided any other basis for his conclusions. Since the cited references are silent as to the pressure of the second vapor, the Appellants submit that the Examiner failed to show that the pressure of the second vapor is result-effective and as such it is not obvious. Therefore, the Examiner has not established a *prima facie* case of obviousness based on the cited prior art, and Claim 16 is patentable over these cited references.

Claim 19

Referring to Claim 19 the Examiner asserts at page 7, lines 1-6 of the Examiner's answer that:

> "the combination of Pessa et al., Hayakawa et al and Ogasawara teaches opening the shutter for 1 second and is silent to the number per surface area of group III atoms form[ing] the monolayer is about 6.5e14 cm^{-2}. The selection of reaction parameters such as temperature and concentration is obvious (In re Aller 105 USPQ 233, 255 (CCPA 1955)). The Flux of a reactant is well known in the art to be a result effective variable. Also the prior art show the amount of time the shutter is open results in more atoms reaching the surface".

Once again, the Examiner overlooks the In re Sebek case and the In re Antonie case. Contrary to the Examiner, "while it may ordinarily be the case that the determination of optimum values for the parameters of a prior art process would be at least prima facie obvious, that conclusion depends upon what the prior art discloses with respect to those parameters." See In re Sebek 465 F.2d 904, 907; 175 USPQ 93, 95 (CCPA 1972). In the case of In re Antonie 559 F.2d 618; 195 USPQ 6 (CCPA 1977), the parameter (treatment capacity) in question was found not to be result-effective because "[t]he experiments suggested by El-Naggar do not reveal the property which applicant has discovered, and the PTO has provided ... [the court] with no other basis for the obviousness of the necessary experiments." See *Id.*, 195 USPQ at 8. Unlike Claim 19, the Examiner concedes that "[t]he combination of Pessa et al, Hayakawa et al and Ogasawara ... is silent to the number per surface area of group III atoms form the monolayer is about 6.5e14 cm^{-2}", see page 7, lines 2-3 of the Examiner's answer, and the Examiner has not provided any other basis for his conclusions. Since the cited references are silent as to the "number per surface area of group III atoms forming the monolayer is about 6.5e14 cm^{-2}" as claimed in Claim 19, the Appellants submit that the Examiner failed to show that the number per surface area of group III atoms forming the monolayer is result-effective and as such it is not obvious. Therefore, the Examiner has not established a *prima facie* case of obviousness based on the cited prior art, and Claim 19 is patentable over these cited references.

3. Claims 17 and 23 - 24 rejected under 35 U.S.C. 103(a) as being unpatentable over Pessa in view of Hayakawa and Ogasawara and further in view of Grunthaner et al., U.S. Patent No. 5,094,974 (hereinafter "Grunthaner")

The Applicant submits that the Examiner has not adequately shown a motivation to combine the references in the manner done by the Examiner. Therefore, the Examiner has not established a *prima facie* case of obviousness based on the cited prior art, and the claim is patentable over these cited references.

4. Claims 32 - 33 rejected under 35 U.S.C. 103(a) as being unpatentable over Pessa in view of Hayakawa and Ogasawara and Grunthaner and further in view of Kubiak et al., U.S. Patent No. 4,330,360 (hereinafter "Kubiak")

The Appellants submit that the Examiner failed to establish a prima facie case of obviousness based on Kubiak, and the claims are patentable over Kubiak. The cited reference Kubiak is improper because it is non-analogous. Kubiak is non-analogous art for the following reasons. Kubiak teaches molecular beam deposition technique using gaseous sources of group V elements. Kubiak discloses "a method and apparatus for growing ... group III-V semiconductor layers on a semiconductor body ... by molecular beam deposition. The group III-V semiconductor layer is formed by directing a group III molecular beam and a group V molecular beam at a semiconductor body". See column 2, lines 10-17. The Examiner correctly states that "it has been held that a prior art reference must either be in the field of applicant's endeavor or, if not, then be reasonably pertinent to the particular problem with which the applicant was concerned, in order to be relied upon as a basis for rejection of the claimed invention". See page 18,

lines 13-16 of the Examiner's answer. The Examiner asserts that "[i]n this case, Kubiak et al teaches a method of growing III-V semiconductors by vaporizing Indium (In) in a molecular beam deposition process ... which is in the same field of endeavor, as appellants, namely introducing a flux In vapor to form a III-V semiconductor of InAs". See page 18, lines 17-20 of the Examiner's answer. The Appellants submit that Kubiak is not in the field of the Applicant's endeavor because Kubiak is in the field of growing group III-V layers on a semiconductor body, whereas the present invention is in the field of growing a buffer layer between two crystals. Appellants can only conclude that the only reason Ogasawara was cited was because the Examiner has performed an *ex post facto* analysis of the Applicant's claims. Kubiak is non-analogous art and a person trying to improve growing an InAs layer on a GaAs substrate would not look to it.

The Applicant further submits that the Examiner did not to establish a *prima facie* case of obviousness of a claimed invention because "it is improper to combine references where the references teach away from their combination" MPEP 2145(X)(D)(2) and In re Grasselli, 713 F.2d 731, 743.

Pessa teaches away from Kubiak for the following reasons. Kubiak discloses "a method and apparatus for growing ... group III-V semiconductor layers on a semiconductor body ... by molecular beam deposition. The group III-V semiconductor layer is formed by directing a group III molecular beam and a group V molecular beam at a semiconductor body". See column 2, lines 10-17. Kubiak does not teach the use of a buffer layer between the group III-V semiconductor layers and a semiconductor body.

Unlike Kubiak, Pessa teaches the growth of the buffer layer ranging in thickness from 40 Å to 3000 Å. See column 4, lines 5-9 of Pessa. It is unclear how the Examiner

expects an ordinary person skilled in the art to combine Pessa and Kubiak when Kubiak does not teach the growth of a buffer layer while Pessa does. How is a person of ordinary skill supposed to deal with this glaring inconsistency of approach? The Examiner should not consider a buffer layer when rejecting Claim 1 and no buffer layer when rejecting Claims 32-33. The Examiner used Applicants' claims as a road map to perform an exhaustive search of putative prior art documents as opposed to considering what the document really teaches to a person skilled in the art. Applicants can only conclude that the only reason Kubiak was cited was because the Examiner has performed an *ex post facto* analysis of the Applicant's claims.

The Examiner is using hindsight to combine a large number of references in a complex manner to arrive allegedly at the claimed invention. The combination proposed by the Examiner is not logical from the reasons stated and there is certainly no motivation for making the suggested combination. Thus Claims 32-33 are patentable over the cited references.

Conclusion

For the extensive reasons advanced above, Appellants respectfully contend that each claim is patentable. Therefore, reversal of all rejections and objections is courteously solicited.

The Commissioner is authorized to charge any additional fees which may be required or credit overpayment to deposit account no. 12-0415. In particular, if this Appeal Brief is not timely filed, the Commissioner is authorized to treat this response as including a petition to extend the time period pursuant to 37 CFR 1.136(a) requesting an extension of time of the number of months necessary to make this response timely filed and the petition fee due in connection therewith may be charged to deposit account no. 12-0415.

I hereby certify that this correspondence is being deposited with the United States Post Office with sufficient postage as express mail in an envelope addressed to: Mail Stop Reply Brief - Patents, Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22323-1450 on

May 18, 2004
(Date of Mailing)

Corinda Humphrey
(Name of Person Mailing)

Corinda Humphrey
(Signature)

May 18, 2004
(Date)

Respectfully submitted,

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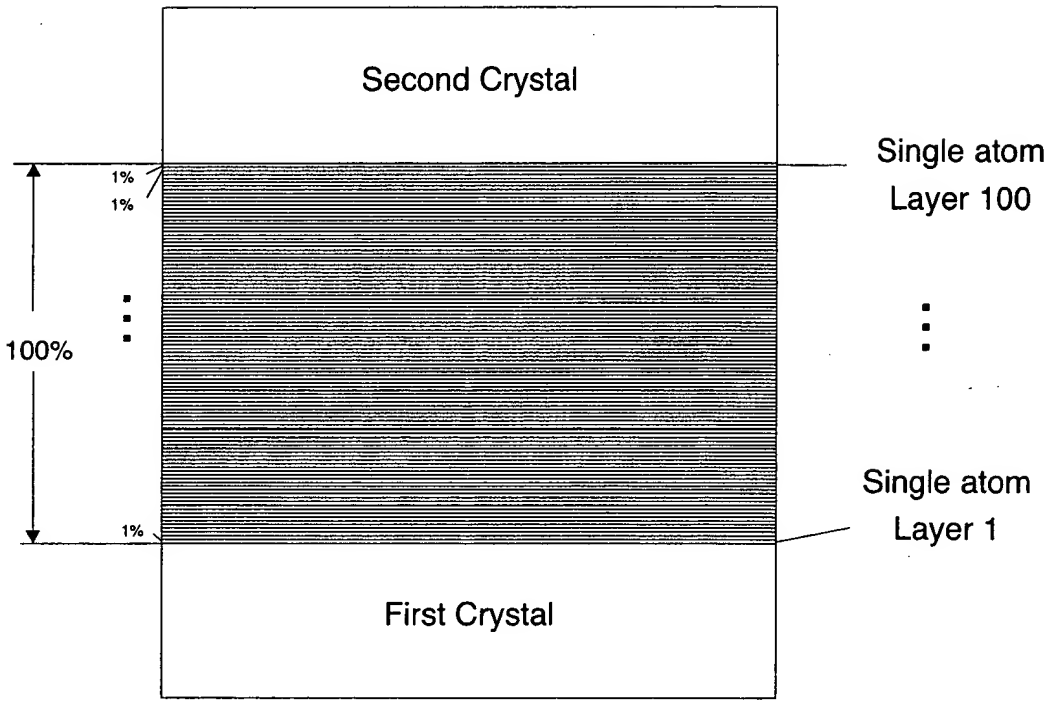

Arsenic

33
As
74.92160(2)

Radii

There are several ways to define radius for atoms and ions. Follow the appropriate hyperlinks for literature references and definitions of each type of radius. All values of radii are given in pm (picometres, or picometers in USA). Conversion factors are:

- 1 pm = 1 x 10^{-12} metre (meter)
- 100 pm = 1 Ångstrom
- 1000 pm = 1 nanometre (nm, nanometer)

AsAs distance in the element

One measure of size is the element-element distance within the element and this length is given here.

View... Go! Bond length in AsAs [/pm]: 249

Neutral radii

The size of neutral atoms depends upon the way in which the measurement is made and the environment. Follow the appropriate hyperlinks for definitions of each radius type. The term "atomic radius" is not particularly helpful although its use is widespread. The problem is its meaning, which is clearly very different in different sources and books. Two values are given here, one is based upon calculations and the other upon observation - follow the appropriate link for further details.

View... Go! Atomic radius (empirical) [/pm]: 115

View... Go! Atomic radius (calculated) [/pm]: 114

View... Go! Covalent radius (empirical) [/pm]: 119

View... Go! van der Waals radius [/pm]: 185

Show elements whose covalent radius is 5 or 50 pm
Sorted ascending by covalent radius Show!

Gallium

31
Ga
69.723(1)

Radii

There are several ways to define radius for atoms and ions. Follow the appropriate hyperlinks for literature references and definitions of each type of radius. All values of radii are given in pm (picometres, or picometers in USA). Conversion factors are:

- 1 pm = 1 x 10^{-12} metre (meter)
- 100 pm = 1 Ångstrom
- 1000 pm = 1 nanometre (nm, nanometer)

GaGa distance in the element

One measure of size is the element-element distance within the element and this length is given here.

View... Go! Bond length in GaGa [/pm]: 244.2

Neutral radii

The size of neutral atoms depends upon the way in which the measurement is made and the environment. Follow the appropriate hyperlinks for definitions of each radius type. The term "atomic radius" is not particularly helpful although its use is widespread. The problem is its meaning, which is clearly very different in different sources and books. Two values are given here, one is based upon calculations and the other upon observation - follow the appropriate link for further details.

View... Go! Atomic radius (empirical) [/pm]: 130

View... Go! Atomic radius (calculated) [/pm]: 136

View... Go! Covalent radius (empirical) [/pm]: 126

View... Go! van der Waals radius [/pm]: 187

Show elements whose covalent radius is ... or ... 50 pm
sorted ascending by covalent radius
Show

Pick element...
Discuss chemistry online!
Definitions
Definition
Literature
Notes
Full table charts
Cityscape
Cylinders
Intensity
Balls
Bars
Lines
QuickDraw 3D
Virtual reality
Flash (new!)
Groups charts
Group 1
Group 2
Group 3
Group 4
Group 5
Group 6
Group 7
Group 8
Group 9
Group 10
Group 11
Group 12
Group 13
Group 14
Group 15
Group 16
Group 17
Group 18
Periods charts
Period 2
Period 3
Period 4 (s, p blocks)
Period 4 (s, p, and d blocks)
Period 4 (d block)
Period 5 (s, p blocks)
Period 5 (s, p, and d blocks)
Period 5 (d block)
Period 6 (s, p

Atomic radius

- Print your own periodic table chart.
- use the periodic table icon link in the left menu bar to navigate to any other element
- select the periodic table logo on the top of the page to restart WebElements

Pictorial representations

Select from the menu to the left to view pictures illustrating the Atomic radius.

Definition

Many references give table of atomic radii. Sometimes in text books and other sources, the rather vague term "atomic radius" is not defined and in such cases it is therefore not clear what the values actually mean. The values given here for atomic radius are calculated values using methods outlined in reference 1.

Units

pm

Notes

These values for atomic radius are calculated values using self-consistent-field functions (reference 1). You should consult reference 1 for full details, but it is not light reading for most people. There is a correlation between the atomic radii as determined from these calculations and the radii of maximum charge density in the outermost shell of the atom.

Literature sources

1. E. Clementi, D.L.Raimondi, and W.P. Reinhardt, *J. Chem. Phys.* 1963, **38**, 2686.